Fracture mapping and feasibility of monitoring CO_2 *in situ* from seismic data at the Mississippian Carbonate Reservoir, Wellington oil field, south-central Kansas

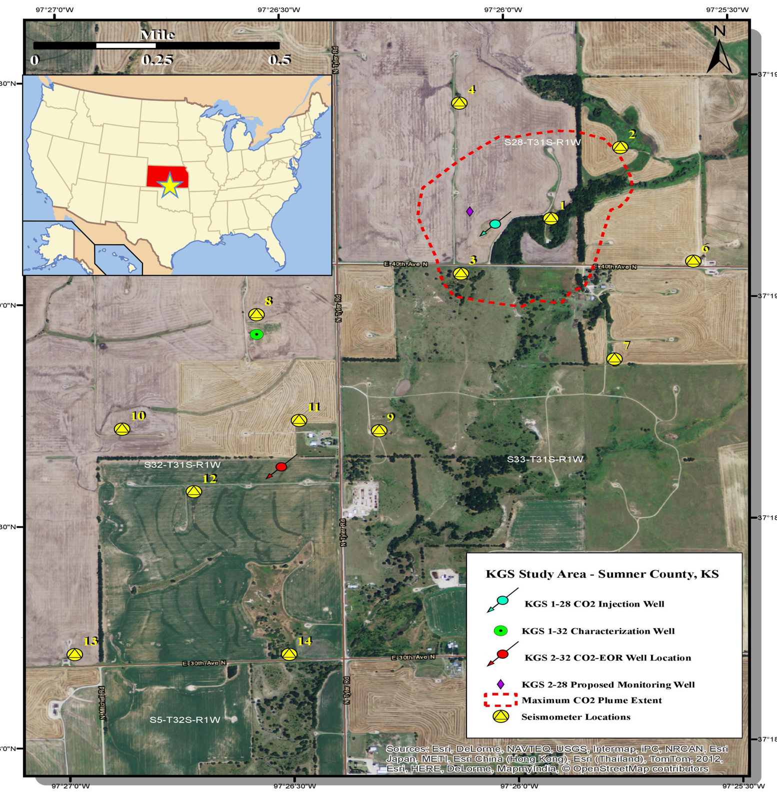
Brandon L. Graham[1], Lauren P. Haga[1], Keith A. Nolte[1], Georgios P. Tsoflias[1], and W. Lynn Watney[2]
[1]Department of Geology, The University of Kansas, Lawrence, KS
[2]Kansas Geological Survey, The University of Kansas, Lawrence, KS

Fracture Mapping

Significance

Analyze the effects of azimuthal anisotropy on 3D P-P wave seismic data to provide insight in the *in situ* stress and relative fracture characteristics of the Mississippian and Arbuckle reservoirs.

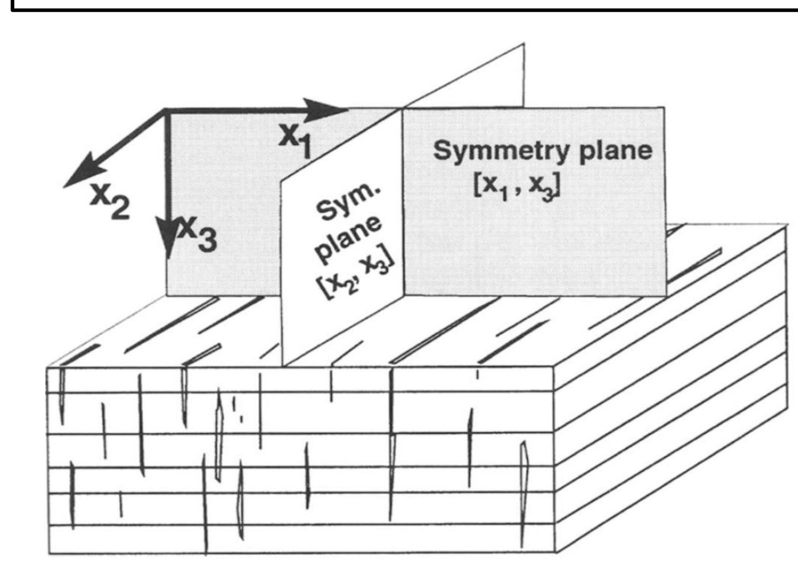
Amplitude variations are analyzed with the azimuth about a common midpoint or common image point in order to quantify reservoir anisotropic properties in the azimuthal domain.



Map view of Wellington oil field, south-central Kansas, with estimated CO_2 plume location.

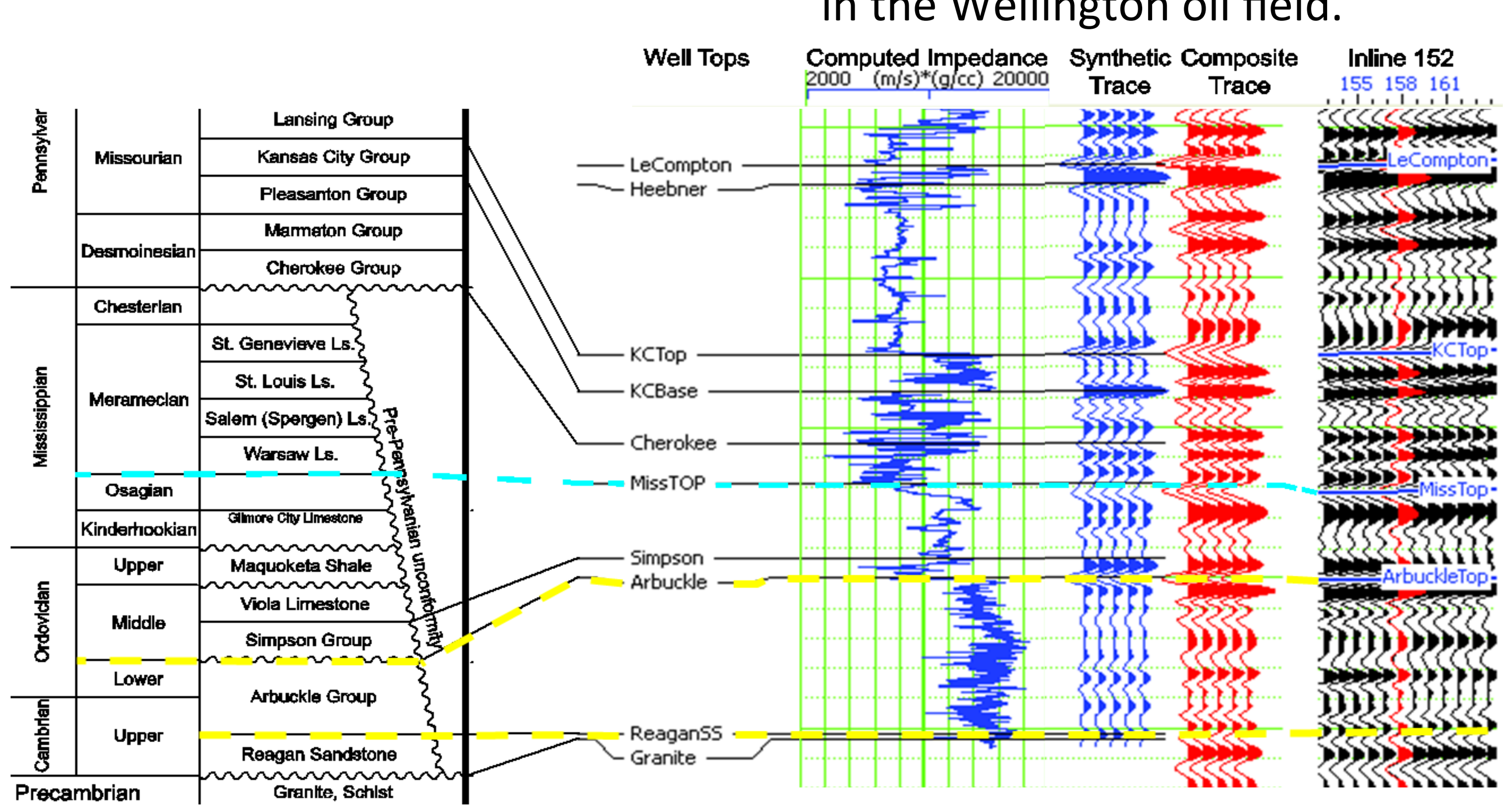
Seismic Anisotropy

- Variations in elastic properties with orientation of wave propagation observed as variation in seismic velocity and amplitude.
- Radial Anisotropy, or Vertically Transverse Isotropy (VTI), is observed in shales and thin layers, and interpreted as Amplitude Variation with Offset (AVO).
- Azimuthal Anisotropy, Horizontal Transverse Isotropy (HTI), is due to *in situ* horizontal stress and vertical fractures.



(left) Conceptual model of both thin horizontal bedding (VTI) and vertical fracture (HTI) creating orthorhombic anisotropy (Ruger, 1998).

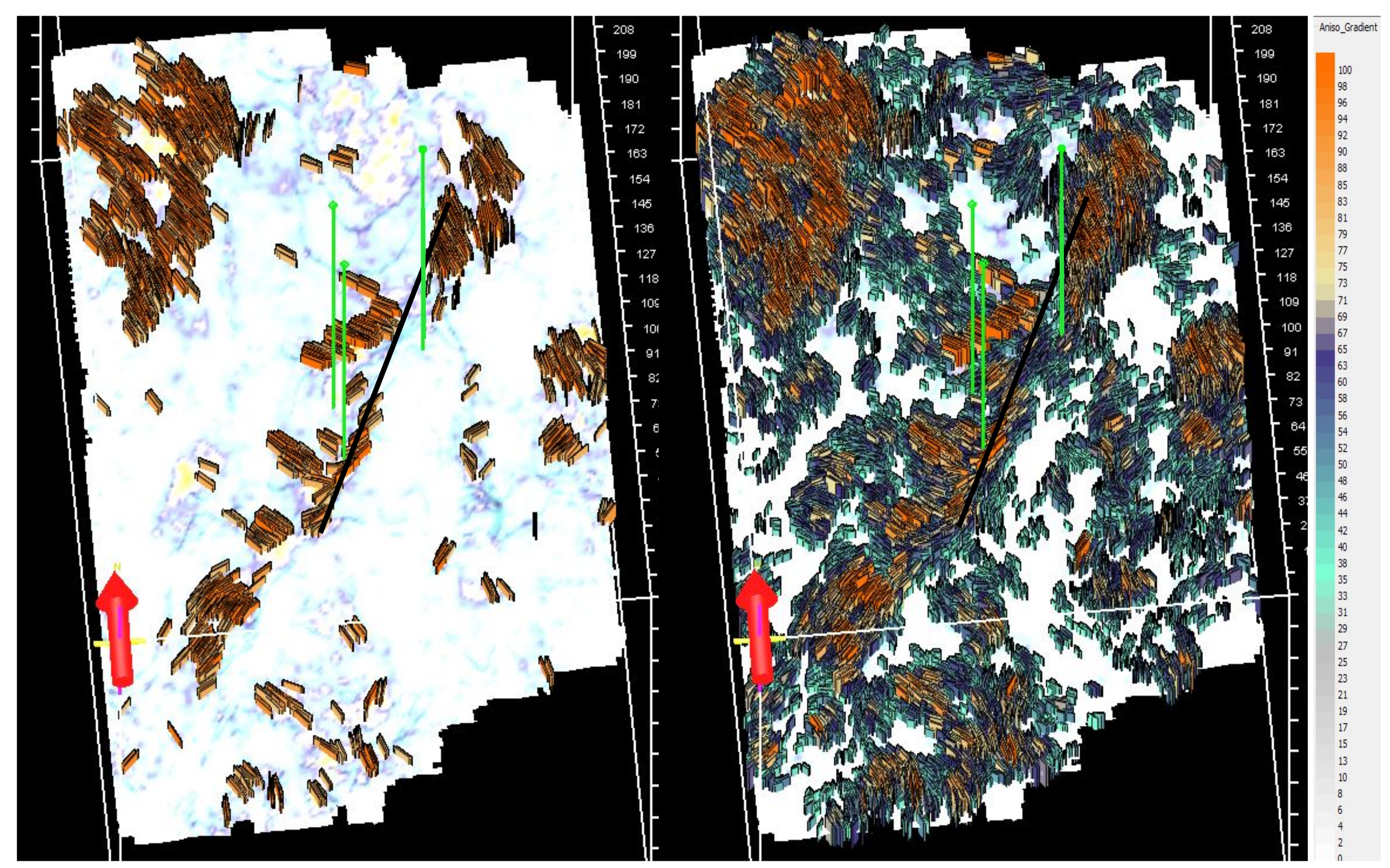
Correlation between seismic data, well logs, and stratigraphy in the Wellington oil field.



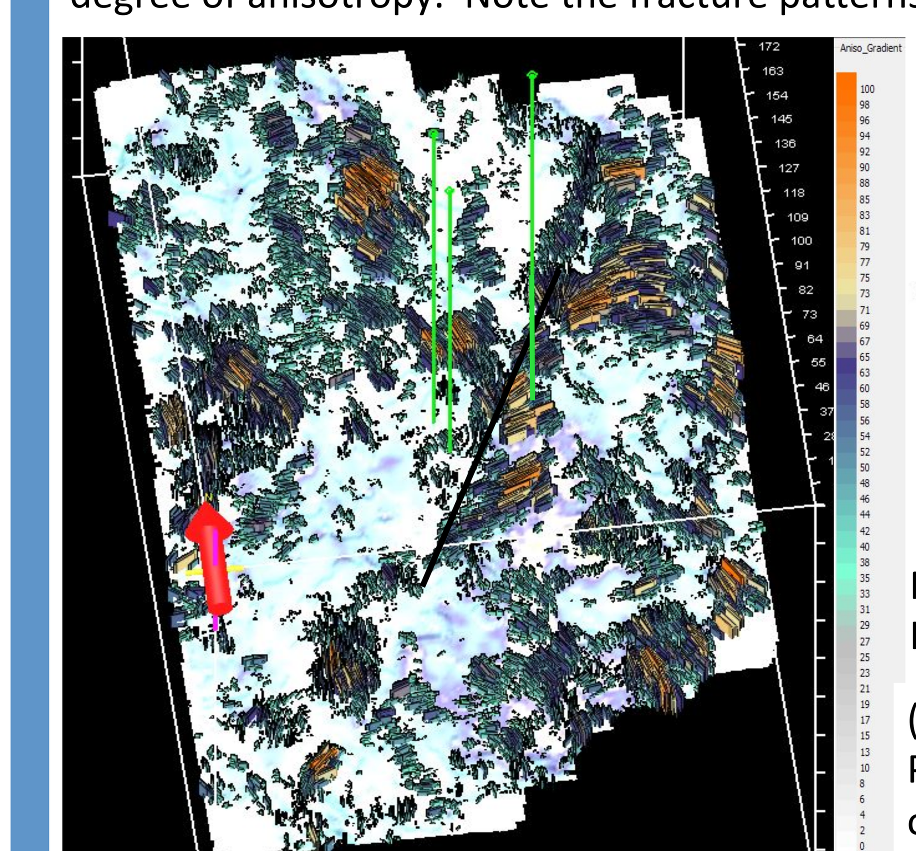
Background

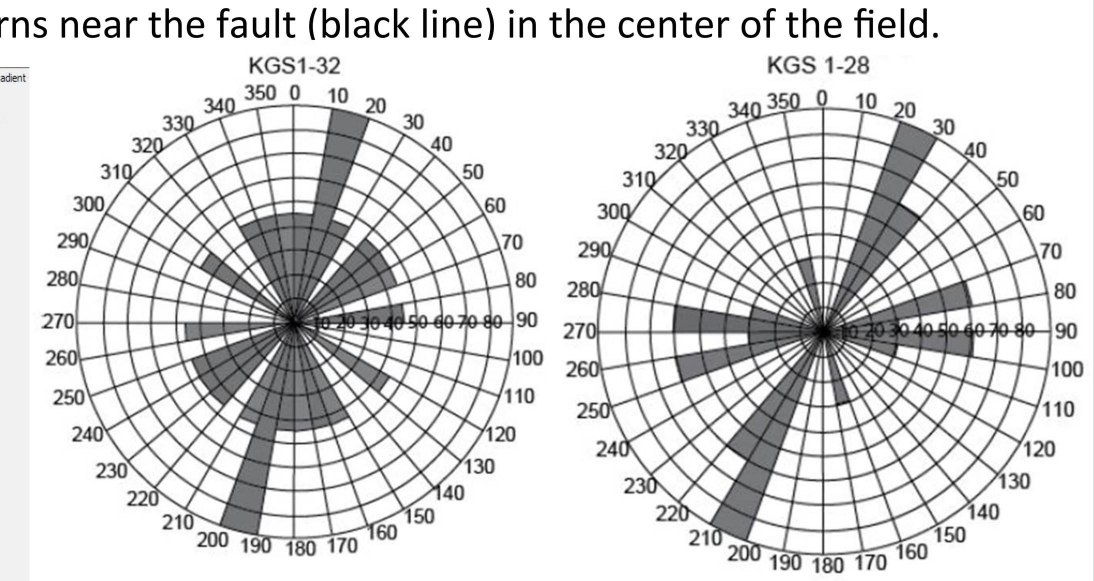
A CO_2 injection pilot study was conducted by the Kansas Geological Survey in spring of 2016 to determine the feasibility of CO_2 for EOR. A 3D seismic survey and two 2D seismic lines were acquired pre-injection, with a final 2D seismic line acquired post-injection.

The Mississippian is a heterogeneous low resistivity-high porosity reservoir, which primarily consists of cherty dolomite. The Arbuckle is comprised of stacked aquifers and aquitards, and is non-producing of oil or gas in the Wellington field (Watney et al, 2001). These carbonates exhibit anisotropy due to varied crystalline structure, porosity geometry, and micro-fracture. The heterogeneity of the reservoirs makes the seismic analysis challenging; however, additional well control and seismic data supplement the modeling effort.



(above) Azimuthal anisotropy results for the top of the Mississippian. The tilted perspective shows the azimuthal planes of isotropy, representing the fracture and stress direction. The size and color of the visible platelets are the degree of anisotropy. The left panel isolates the highest degree of anisotropy to aid in visualizing the predominant fracture orientation, while the right panel shows the moderate to high degree of anisotropy. Note the fracture patterns near the fault (black line) in the center of the field.





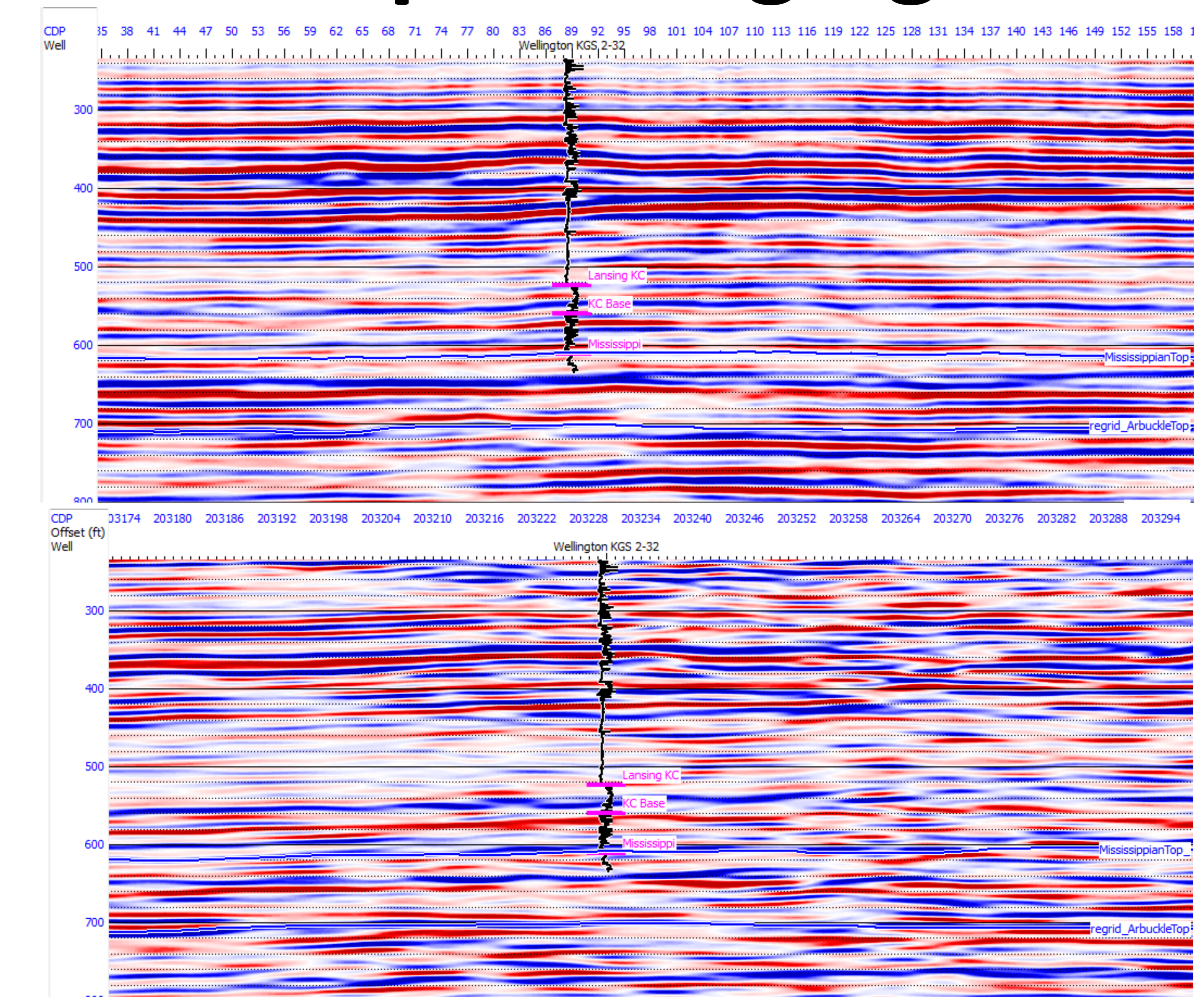
Natural open fractures observed in FMI Logs in well KGS 1-32 (left) and 1-28 (right). Image from Schwab 2016.

(left) Azimuthal anisotropy results for the Arbuckle. Predominant fracture patterns are similar to trends observed in the Mississippian as maximum horizontal stress and fracture orientations determined from Schwab (2016). The fault (black line) is similarly observed by the accompanying fracture pattern.

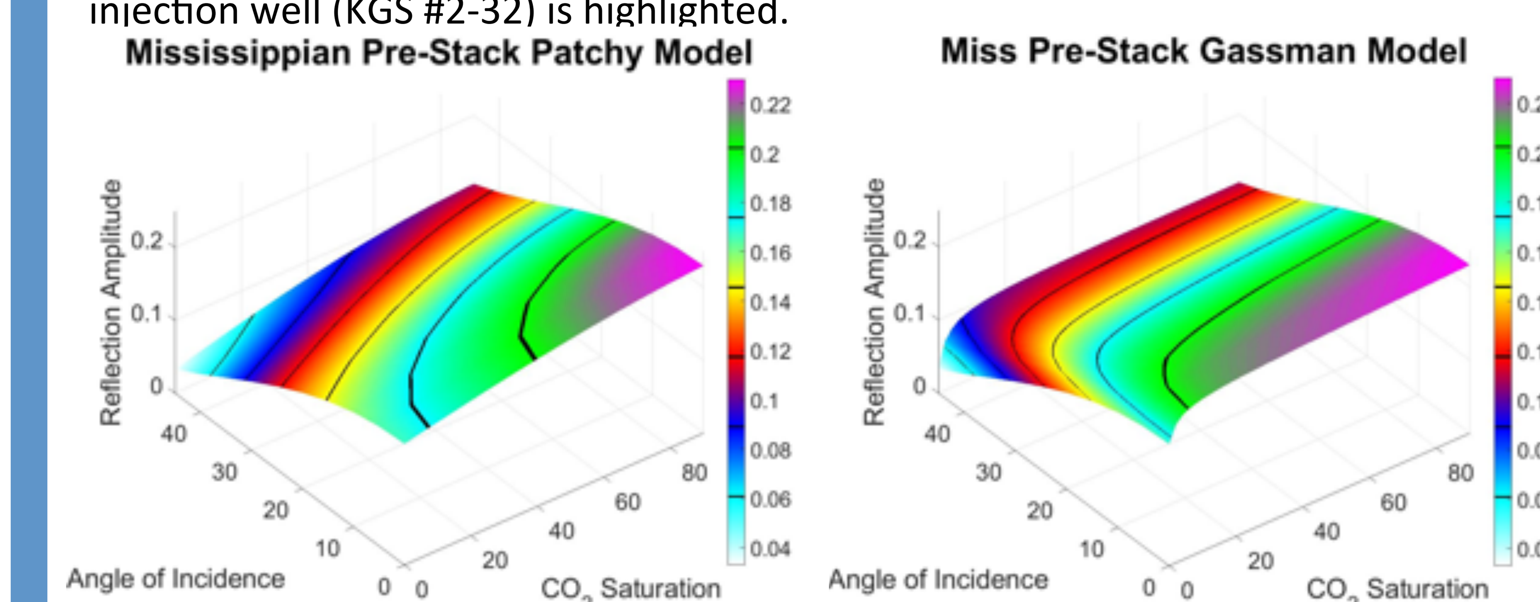
Conclusions

- Analysis of azimuthal anisotropy of the Mississippian and Arbuckle exhibits results consistent with fracture and maximum horizontal stress direction.
- Large scale features such as faults are indirectly observed through AVAz

Time lapse imaging of CO_2



Comparison of the arbitrary line extracted from the 3D pre-CO_2 injection seismic survey (top), and the 2D post-CO_2 injection seismic line (bottom). The zone of interest is the Mississippian reservoir located from 610-700 milliseconds. The injection well (KGS #2-32) is highlighted.



Patchy model (bottom left) and Gassmann model (bottom right) for the Mississippian reservoir

Conclusions

- Post-stack seismic amplitude analysis for CO2 detection is inconclusive, however this is not unexpected given the relatively small amount of CO2 injected and high matrix incompressibility.
- Gassmann and Patchy fluid substitution models for the Mississippian reservoir display a decrease in amplitude with an increasing angle of incidence and CO2 saturation.
- Use of AVO and impedance inversion in the pre-stack domain will be employed to test the utility of surface seismic for detecting the CO2 plume and to verify fluid substitution modeling results.

Acknowledgements

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References

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